FIRST RESULTS FROM A SEARCH FOR TEV EMISSION FROM BL LACS OUT TO Z=0.2

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ABSTRACT

Two active galactic nuclei have been detected at TeV energies using the atmospheric Čerenkov imaging technique. The Whipple Observatory γ-ray telescope has been used to observe all the BL Lacertae objects in the northern hemisphere out to a redshift of 0.1. We report the tentative detection of VHE emission from a third BL Lac object, 1ES 2344+514. Progress in extending this survey out to z=0.2 will also be reported.

INTRODUCTION

With the detection of very high energy (VHE, $E > 250$ GeV) emission from the two BL Lacertae objects (BL Lacs) , Markarian 421 (Mrk 421) (Punch et al. 1992) and Mrk 501 (Quinn et al. 1996), we began a survey of nearby BL Lacs to search for VHE emission. A collection of such sources could lead to constraintes on γ-ray emission models through investigation into the properties which are important for VHE emission and also an estimate of the density of extragalactic background IR light through its effect on the VHE γ-ray spectra (Gould and Schréder 1967; Stecker, de Jager, & Salamon 1993).

BL Lacs are blazars, the only type of active galactic nucleus (AGN) detected above 100 MeV. The electromagnetic spectrum of blazars consists of synchrotron emission, which spans radio to UV or X-ray wavelengths, produced by electrons moving within jets oriented at small angles to our line of sight (Blandford & Königl 1981), and a high energy part which can extend to γ-ray energies. Models of the high energy emission fall into three main categories: synchrotron self-Compton emission (e.g., Königl 1981), inverse-Compton scattering of low energy photons arising outside the jet (e.g., Sikora, Begelman, and Rees 1994), and pair cascades initiated by protons (Mannheim 1993) or electrons. If protons produce the high energy emission, AGN could contribute significantly to the highest energy cosmic-ray flux ($E > 10^{18}$eV) (Rachen, Stanev, and Biermann 1993).

BL Lacs are particularly promising candidates for VHE emission because of two aspects of their low energy emission. First, BL Lacs may have less γ-ray absorbing material near the source because they have weak or no emission lines in their optical spectra (Dermer and Schlickeiser 1994). Second, in inverse Compton (IC) models of the high energy emission, the extension of the synchrotron emission of X-ray selected BL Lacs (e.g., Mrk 421 and Mrk 501) into the X-ray waveband implies a higher maximum γ-ray energy than for radio-loud BL Lacs (e.g., W Comae) and flat spectrum radio quasars (e.g., 3C 279) where the synchrotron emission ends in the optical to UV range.

Table 1 lists the objects observed in our BL Lac survey so far. We have limited our search to BL Lacs with $z < 0.2$ to reduce the effects of γ-ray absorption on background IR light. We observed

extending our survey out to z=0.2. We applied a two-part approach to the survey. First, we selected a few promising candidates for long exposures to search for low-level VHE γ-ray emission, such as was observed with Mrk 501 in its initial detection (Quinn et al. 1996). Second, the remaining objects were observed for less total time, but the observations were spread out over a long time period in order to maximize the chance that we might see an episode of high emission, such as has been seen in Mrk 421 (Gaidos et al. 1996) and Mrk 501 (Quinn et al. 1996). This latter approach led to the likely detection of a third VHE-emitting BL Lac, 1ES 2344+514.

OBSERVATIONS AND ANALYSIS

The VHE observations reported in this paper were made with the atmospheric Čerenkov imaging technique (Cawley and Weekes 1995) using the 10 m optical reflector located at the Whipple Observatory on Mt. Hopkins in Arizona (elevation 2.3 km). The high resolution camera, consisting of 109 photomultiplier tubes, is mounted in the focal plane of the reflector and records images of atmospheric Čerenkov radiation from air showers produced by γ-rays and cosmic rays (Cawley et al. 1990). The energy threshold of the observations reported here is 350 GeV.

Čerenkov light images are classified according to their angular size and orientation. γ-ray images are typically smaller and more elliptical than background hadronic images and they are preferentially oriented toward the source location. The basic data selection was based on the Supercuts criteria (Reynolds et al. 1993). However, some modifications have been made to account for changes to the telescope which reduced the detector energy threshold and increased the background from event triggers caused by fluctuations in night-sky background light and Čerenkov events caused by single local muons (see Catanese et al. 1996 for details).

The results reported in this paper use a *Tracking* analysis wherein events whose orientations do not point toward the object's direction are used to determine the background level. A large collection of non-source data, consisting of off-source observations and non-detected objects other than BL Lacs, were combined to estimate the factor which converts the off-source events to a background estimate. The count rates are converted to integral fluxes by expressing them as a multiple of the Crab Nebula count rate and then multiplying that fraction by the Crab Nebula flux, $I(> 350\ \mathrm{GeV}) = 8.7 \times 10^{-11}$ photons cm^{-2} s^{-1} (Hillas et al. 1997). This procedure assumes that the Crab Nebula VHE γ-ray flux is constant, as 7 years of Whipple Observatory data indicate (Hillas et al. 1997), and that the object's photon spectrum is identical to that of the Crab Nebula between 0.3 and 10 TeV, $dN/dE \propto E^{-2.4}$ (Hillas et al. 1997), which may not be the case. If no significant emission is seen from a candidate source, a 99.9% confidence upper limit is calculated using the method of Helene (1983).

RESULTS

In Table 1 we present the results of observations for which the analysis has been completed. With the exception of 1ES 2344+514, there is no evidence of emission from any of the objects in this survey. In particular, the EGRET sources W Comae (von Montigny et al. 1995) and BL Lacertae (Catanese et al. 1997a) are not detected despite long exposures. Also, only 1ES 2344+514 shows evidence of short term activity.

Most of the excess from 1ES 2344+514 during 1995 comes from an apparent flare on 1995 December 20 (see Figure 1). We find a non-statistically significant excess from this object in 1996 which could simply mean that the average flux level dropped below the telescope sensitivity limit, as occasionally happens with Mrk 421 (Buckley et al. 1996). We currently consider the detection tentative because we see no evidence for a consistent signal nor is there independent confirmation of a high state for this object (e.g., from X-ray observations) during this period.

Object	z	Type[a]	Observ. Epoch	Exp. (hrs)	Excess	Max. Daily Exc.	Flux (Crab)[b]	Flux[c]
1ES 2344+514	0.044	X	1995/96	20.5	5.3σ	6.0σ	0.16$\pm$0.03	1.4$\pm$0.3
			20-12-95	1.8	6.0σ		0.63$\pm$0.11	5.5$\pm$1.0
			1996	32.1	1.6σ	2.1σ	<0.081	<0.70
Markarian 180	0.046	X	1996	20.9	-0.4σ	0.6σ	<0.105	<0.91
1ES 1959+650	0.048	X	1996	3.7	0.3σ	1.2σ	<0.128	<1.10
3C 371	0.051	R						
I Zw 187	0.055	X	1996	2.3	0.6σ	1.2σ	<0.150	<1.30
1ES 2321+419	0.059?	X?	1996	6.4	-1.3σ	0.3σ	<0.106	<0.92
BL Lacertae[d]	0.069	R	1995	39.1	-1.0σ	0.5σ	<0.06	<0.53
1ES 1741+196	0.083	X	1996	8.8	-1.7σ	0.6σ	<0.046	<0.40
W Comae	0.102	R	1996	16.6	-0.4σ	1.4σ	<0.056	<0.47
1ES 0145+138	0.125	X						
EXO 0706.1+5913	0.125	X						
1H 1219+301	0.130	X						
1H 1430+423	0.130	X						
1ES 0229+200	0.139	X						
1ES 1255+244	0.141	X						
1H 0323+022	0.147	X						
1ES 0927+500	0.188	R						

[a]Indicates whether the object is radio selected (R) or X-ray selected (X).
[b]Flux, or upper limit, is expressed in units of the Crab Nebula flux.
[c]Integral fluxes or upper limits are quoted above 350 GeV in units of $10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Flux upper limits are at the 99.9% confidence level.
[d]Results from Catanese et al. 1997a.

CONCLUSIONS

Both Mrk 421 and Mrk 501 have energy spectra, expressed as νF_ν, with peaks of comparable amplitude at the X-ray and γ-ray energies (Buckley et al. 1996; Catanese et al. 1997b). If the X-ray selected BL Lacs in this sample are similar to Mrk 421 and Mrk 501, an upper limit below the X-ray power output would indicate some reduction of the VHE flux at the source or en-route to Earth. Our current limits are not below the lowest measured X-ray fluxes for these objects. Further observations will be needed to clearly establish whether these objects emit VHE γ-rays at the expected levels.

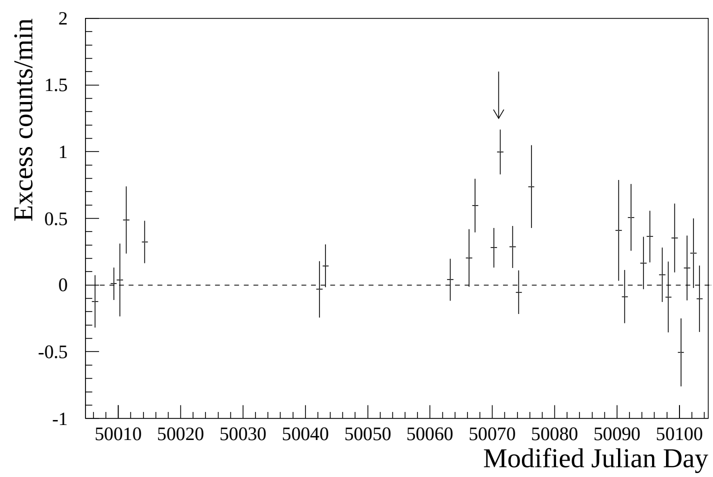

Fig. 1: The light curve for γ-ray observations of 1ES 2344+514 between Oct. 1995 and Jan. 1996. The flare on 20-12-1995 is indicated by the arrow.

For the two EGRET sources in this survey, W Comae and BL Lacertae, the Whipple upper limits are well below the power output at EGRET energies (see Figure 2 and Catanese et al. 1997a). This is

waveband and so would have lower maximum γ-ray energies. However, the VHE observations are not contemporaneous, so it may be that the γ-ray emission was in a low state when these objects were observed at the Whipple Observatory. Also, the VHE γ-ray emission from W Comae may have been attenuated significantly by the IR background because its redshift is 0.102.

Finally, the detection of 1ES 2344+514, if confirmed, would be consistent with the other detected VHE blazar sources: it is a nearby X-ray selected BL Lac (the third closest known) whose γ-ray emission is variable.

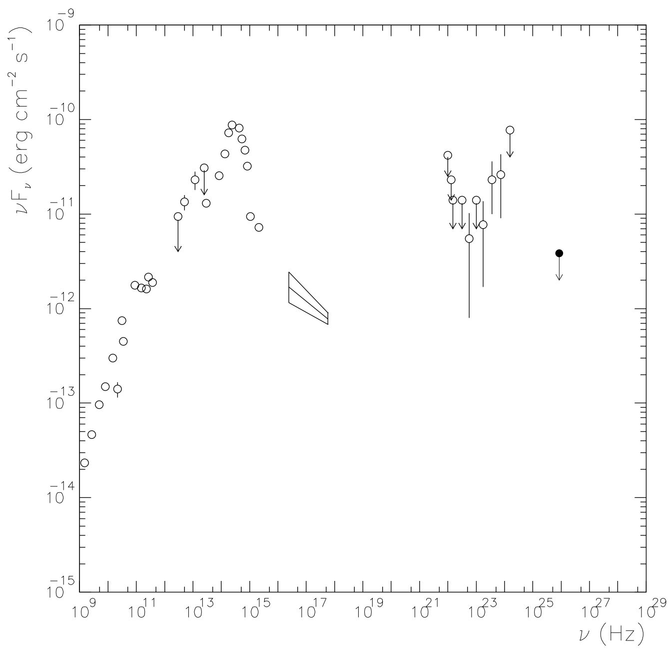

Fig. 2: Spectral energy distribution of W Comae. Shown are the VHE upper limit (filled circle) and archival data (open circles) (von Montigny et al. 1995; Lamer, Brunner and Staubert 1996; Edelson et al. 1992; Cruz-Gonzalez and Huchra 1984; Impey and Neugebauer 1988; Gear et al. 1994; Owen, Spangler, and Cotton 1980).

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